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## Research Article

# Self-Esteem as a Complex Dynamic System: Intrinsic and Extrinsic Microlevel Dynamics

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The variability of self-esteem is an important characteristic of self-esteem. However, little is known about the mechanisms that underlie it. The goal of the current study was to empirically explore these underlying mechanisms. It is commonly assumed that state self-esteem (the fleeting experience of the self) is a response to the immediate social context. Drawing from a complex dynamic systems perspective, the self-organizing self-esteem model asserts that this responsivity is not passive or stimulus-response like, but that the impact of the social context on state self-esteem is intimately connected to the intrinsic dynamics of self-esteem. The model suggests that intrinsic dynamics are the result of higher-order self-esteem attractors that can constrain state self-esteem variability. The current study tests this model, and more specifically, the prediction that state self-esteem variability is less influenced by changes in the immediate context if relatively *strong*, as opposed to weak, self-esteem attractors underlie intrinsic dynamics of self-esteem. To test this, parent-adolescent dyads ( $N = 13$ ,  $M_{\text{age}} = 13.6$ ) were filmed during seminaturalistic discussions. Observable components of adolescent state self-esteem were coded in real time, as well as real-time parental autonomy-support and relatedness. Kohonen's self-organizing maps were used to derive attractor-like patterns: repeated higher-order patterns of adolescents' self-esteem components. State space grids were used to assess how much adolescents' self-esteem attractors constrained their state self-esteem variability. We found varying levels of attractor strength in our sample. In accordance with our prediction, we found that state self-esteem was less sensitive to changes in parental support and relatedness for adolescents with stronger self-esteem attractors. Discussion revolves around the implications of our findings for the ontology of self-esteem.

## 1. Introduction

Individuals differ not only in their level of self-esteem but also in the extent to which their self-esteem is variable over time. The variability of *state self-esteem*, that is, the fleeting and in-the-moment experience of the self as positive or negative [1], has been found to be a critical factor associated with depression proneness [2], anger arousal, and hostility [3], as well as reactions to evaluative feedback [4] and self-concept clarity or integration [5, 6]. While the pervasive importance of state self-esteem variability is clear, it is as yet unclear from where state self-esteem variability, and individual differences

therein, stems. There are broadly speaking two streams of research concerning state self-esteem, both pointing toward different explanations for state self-esteem variability. As we will describe below, there appears to be a theoretical and methodological chasm between these two streams of research. While each of them has contributed important understanding of self-esteem as a process, each neglects the other.

The common conceptualization of state self-esteem focuses on the role of *extrinsic* forces in bringing about variability of state self-esteem. This assumption is the cornerstone of the dominant conceptualization in the field, that is, the Sociometer Theory of Self-Esteem [7]. From this

perspective, state self-esteem fluctuates around a resting baseline level [8] in response to “incoming information relevant to relational evaluation” ([9], p. 2), and it is seen as a “subjective index or marker of the degree to which the individual is being included versus excluded by other people” ([10], p. 519). As a result, “cues that connote high relational evaluation raise state self-esteem, whereas cues that connote low relational evaluation lower state self-esteem” ([9], p. 2). Within this line of research, researchers investigate whether state self-esteem increases and decreases after (usually *social*) cues, such as randomly assigned “bogus” approval or judgement from “peers” (Thomaes et al., 2010), imagined evaluations from peers (Leary et al., 1998), subliminally presented words [11], real-life academic or peer problems (Reynolds and Repetti, 2008), social exclusion (during a study-exchange abroad; [12]), or global negative events [13]. In focusing on the reactivity of state self-esteem to the social context, the *intrinsic* forces acting upon state self-esteem have not received any attention within this line of research.

In contrast, emerging studies that utilize time series analyses focus solely on these intrinsic forces. These studies have shown that state self-esteem exhibits internally generated patterns of change (referred to as the *intrinsic dynamics* of a process; [14]) across the real-time time span (i.e., from moment to moment; [15, 16]) and across months [17, 18]. These studies found that self-esteem resembles a “fractal process,” characterized by long-range correlations and nonstationarity. This is an important finding, as fractal processes sharply contrast the kind of process one would expect from fluctuations around a stable baseline in response to temporally independent contextual cues (i.e., the common conceptualization). This was explicitly tested and shown in De Ruiter et al. [15]. These studies have thus brought attention to the necessity of investigating the intrinsic dynamics of state self-esteem. However, in focusing on the temporal structure of state self-esteem processes, they too have failed to examine the whole picture, where they have ignored (methodologically) the role of the extrinsic forces acting upon state self-esteem.

The aim of the current article is to demonstrate that state self-esteem variability emerges from the *interplay* between intrinsic and extrinsic forces. We suggest that this can best be understood from the perspective that self-esteem functions as a complex dynamic system, where state self-esteem variability is a microlevel process that emerges from a dynamic interplay between perturbations from the immediate context (i.e., extrinsic forces) and higher-order self-esteem attractors (i.e., intrinsic forces). By studying the interplay between intrinsic and extrinsic forces, we aim to extend the emerging research on the intrinsic dynamics of state self-esteem [15–18] and to provide support for the emerging conceptualization of state self-esteem as part of a complex dynamic system.

We explore the interplay between intrinsic and extrinsic forces based on the predictions stemming from the self-organizing self-esteem model [19]. This is a theoretical model of self-esteem as a complex dynamic system, and it explains the precise nature of “intrinsic dynamics” in self-esteem, and how the interaction between intrinsic dynamics and contextual forces can bring about state self-esteem variability [19].

In empirically testing these predictions, we explore how pivotal properties of a complex dynamic system may be empirically studied in the field of self-esteem, including nested timescales of development, circular causality, bottom-up emergence of attractor-like patterns, and top-down constraint on lower-order variability. In this exploratory study of these processes, our aim is to generalize from data description to theory (of complex dynamic systems), rather than to a description of the population [20].

*1.1. The Nature of the Intrinsic Dynamics of Self-Esteem.* The self-organizing self-esteem model [19] asserts that state self-esteem is dynamically nested within a larger self-esteem system. State self-esteem experiences are the lower-order process within this system. State self-esteem experiences feed forward across time, eventually giving way to the emergence of a more stable higher-order pattern of self-esteem. These higher-order patterns of self-esteem then constrain the future variability of state self-esteem in such a way that the moment-to-moment development of state self-esteem is pulled in the direction of the existing higher-order self-esteem patterns and away from alternative kinds of self-esteem experiences. Together, these processes are part of a continuously bidirectional causal process (i.e., circular causality; Haken, 1997).

From a complex dynamic systems perspective, these higher-order patterns are formally referred to as *attractor states*. These are any highly absorbing states to which a system (which can be psychological system within a person, such as self-esteem, or a dyad, a family, or a society) frequently returns because only a small amount of energy is needed to maintain that pattern [21–23]. In this way, attractor states can be thought of as tendencies or habits.

Furthermore, more than one attractor state can emerge in a bottom-up fashion across time, where each one is a qualitatively different tendency or habit (i.e., multistability). Together, they form a larger *attractor landscape*. Each attractor within the landscape provides a separate set of top-down constraints on the system’s lower-order processes.

The process of circular causality is often illustrated with an *epigenetic landscape*, consisting of valleys and a moving ball (see Figure 1). Each valley represents a different attractor state that pulls lower-order development (i.e., the movements of the ball) in a different direction.

The landscape illustrates that the lower-order process (i.e., the ball) is more likely to roll into the wider valleys, as more conditions lead to this point. Once in a valley, the deeper the valley the more energy that is needed to remove the ball from the valley. Wider and deeper valleys thus represent stronger attractor states that have a larger “pull” on the moment-to-moment variability of the lower-order process. Stronger attractor states are those that have become more entrenched across time [24, 25].

In the current article, we focus on two properties of the attractor landscape in our illustration of self-esteem as a complex dynamic system. First, the notion that a system is characterized by an attractor landscape highlights that individuals may have more than one self-esteem tendency. This is in contrast with the common idea that individuals have

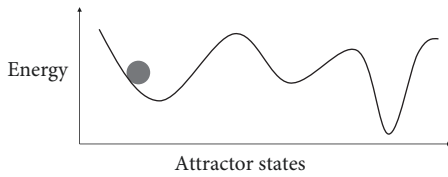


FIGURE 1: An attractor landscape, consisting of coexisting attractor states. Each attractor state is represented by a valley that provides a unique set of constraints on the movements of the ball. These movements represent the variability of lower-order components of the system. From De Ruiter et al. [19].

one baseline level of self-esteem [8, 10]. For example, if an individual systematically fluctuates between experiencing very high and very low state self-esteem, the iterative experience of these two qualities of state self-esteem will eventually give way to two relatively stable tendencies of self-esteem (i.e., very low and very high). Within any given situation, this specific individual will thus be drawn toward two competing tendencies of self-esteem (i.e., two attractors).

The second property of the attractor landscape that we will focus on is the constraining effect that an individual's self-esteem attractor landscape has on lower-order processes of self-esteem. Higher-order self-esteem attractors limit the degrees of freedom of state self-esteem variability. In this way, an individual's state self-esteem process (and specifically, the valence of this process, where the individual can experience himself as relatively negative or positive) is "drawn to" these self-esteem tendencies in real time. If the individual has a deeply entrenched attractor for high self-esteem and a weak attractor for low self-esteem, his state self-esteem process will be more strongly pulled toward positive valence.

The constraining effect that self-esteem attractors have on the valence of moment-to-moment self-experiences has been demonstrated empirically in a study of real-time self-evaluative narratives [26]. In this study, individuals' self-narratives were recorded, and afterwards the individuals mapped the moment-to-moment changes in valence that occurred during their self-narratives. The study showed that the flow of individuals' self-narratives was structured by their person-specific landscape of self-evaluation attractors. Moreover, there were clear individual differences in the quality of individuals' attractors (i.e., positive or negative) and in the constraint that these attractors had, predicted by individual differences in self-concept clarity. The study therefore showed that temporal variability in self-narratives is constrained by an individual's self-evaluation attractor landscape.

**1.2. The Interplay between Intrinsic Dynamics and Contextual Forces.** A key aspect of the self-organizing self-esteem model, and focus in this article, is the notion that self-esteem attractors that are relatively entrenched will inflict greater constraint on the moment-to-moment variability of state self-esteem. The SOSE model predicts that, as a consequence of this, it will be more difficult for the immediate social context to perturb the flow of state self-esteem from its current

position given more entrenched (i.e., stronger) self-esteem attractors. There is therefore a constant interplay between these two forces acting upon state self-esteem. As a result, we suggest that the "reactivity" of state self-esteem to social cues must be seen in the context of the strength of self-esteem attractors. This is portrayed in Figure 2.

For individuals with relatively weak self-esteem attractor states, these attractor states will provide lower constraint on the moment-to-moment variability of state self-esteem. As a result, it will be relatively easy for the immediate social context to perturb the flow of state self-esteem and to move it from its current position, resulting in more reactivity [19].

While studies frequently find that state self-esteem is particularly responsive to the social context ([12]; Leary et al., 1998; Reynolds and Repetti, 2008; Thomaes et al., 2010), the SOSE model extends this by predicting that individual differences in the degree of attractor states' entrenchment will have direct consequences for how *easily* the social context will trigger changes in state self-esteem.

In linking properties of self-esteem attractor landscapes to individual vulnerability to changes in the social context, this prediction describes the mechanism potentially underlying previous findings involving self-esteem and low *self-concept clarity* (i.e., lack of a clear—integrated, consistent, or certain—sense of self). Low self-concept clarity has been found to correspond with higher levels of temporal variability of self-esteem (Nezlek and Plesko, 2001; [16]) and more unstable and abrupt shifts in self-esteem [26]. As Wong et al. [26] have suggested, this indicates that low self-concept clarity may be the signal of "weak attractors ..., such that the self-system cannot settle on specific states of self-esteem that provide stable frames of reference for thought, feeling, and action" ([26], p. 168). Furthermore, lower self-concept clarity is associated with more temporal instability of self-esteem [27]. From our framework, this can be explained by weaker self-esteem attractors, as weak attractors provide a low level of constraint on state self-esteem processes, leaving them more vulnerable to daily events. This would provide an explanation for the more general finding that self-feelings of individuals with unstable (as opposed to stable) self-esteem are more impacted by daily negative events [28–30].

**1.3. The Current Study: Empirically Testing the Interplay between Intrinsic Dynamics and Contextual Forces.** Based on the abovementioned conceptualization and predictions, we hypothesize that there will be a negative within-individual relationship between the level of self-esteem attractor constraint and the influence that the social context will have on state self-esteem: for individuals whose self-esteem attractors have *more* constraint on their state self-esteem variability (i.e., stronger self-esteem attractors), state self-esteem will be *less* affected by contextual changes. In contrast, in individuals whose self-esteem attractors exhibit *less* constraint on their state self-esteem variability (i.e., weaker self-esteem attractors), state self-esteem variability will be *more* affected by contextual changes. This study focuses specifically on self-esteem processes of adolescents, as adolescence is a significant period for self-esteem development

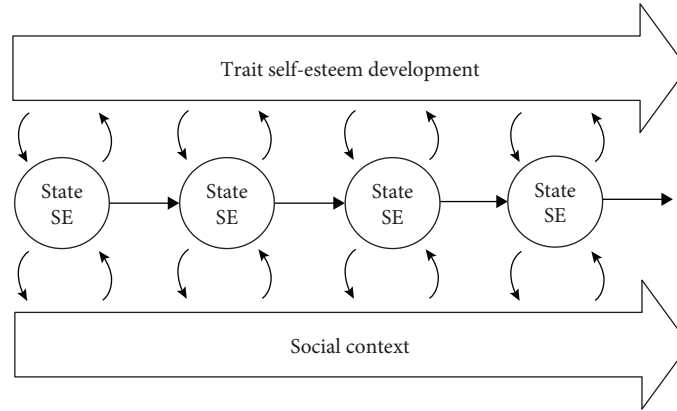


FIGURE 2: Two forces acting upon state self-esteem (SE): self-esteem attractors have a degree of constraint on state self-esteem variability, and the immediate social context can perturb state self-esteem variability (adapted from [19]).

[31]. In the following section, we outline the empirical approach that is taken in order to test this hypothesis.

In accordance with Gelman's (2017) recommendations, we focused our data-collection efforts on the quality (i.e., relevance and accuracy) of our measures, design, and analyses in relation to our test of specific theoretical predictions, rather than, for example, larger sample sizes to infer population tendencies. Given our goal to explore real-time processes and to use these descriptions to support a theoretical idea (rather than a generalization to the population), the intensive real-time data collected and methods utilized were highly suited to our specific research aim.

**1.3.1. State Self-Esteem: An Observational Approach.** Currently, studies that use high-frequency measures of state self-esteem across time have intervals of half a day or a day between measures (e.g., [5, 12]). Such studies use the common self-report method to measure state self-esteem, therefore operationalizing self-esteem as the primarily *cognitive* experience of one's self-concept as positive or negative.

For our purpose of studying *real-time* variability of state self-esteem, it is intuitively no longer valid to assume that individuals actively reflect on the valence of their self-worth from moment to moment. Instead, the nature of self-esteem at this timescale is more social and emotional and should be measured as such [32]. Moreover, the very act of reporting on the momentary experience of one's self would disrupt the organic and continuous process of state self-esteem experiences and thus the intrinsic dynamics that we are studying. To remedy this, we must therefore adopt a novel methodological approach to the measurement of state self-esteem processes.

Previous researchers have suggested that using an observational method provides a valid measure of self-esteem, especially in the case of adolescents (who may be prone to self-enhancement tendencies; [32–34]). Furthermore, this approach provides a fine-grained measure for the moment-to-moment dynamics of self-esteem without interrupting those dynamics as they unfold over time. In the current study we, we therefore take an observational approach to adolescents' real-time self-esteem. We investigated adolescents'

self-esteem in the context of dyadic interaction with parents. Parents are a key significant other for adolescents' self-esteem [35, 36], thus providing a practical and theoretically valid way to elicit relevant self-esteem processes [37].

We measured two underlying components of adolescents' global self-esteem that can be observed during interactions with their parents. Self-esteem is thought to have two dimensions, self-liking and self-competence. *Self-liking* refers to the experience of oneself as a good or bad social object according to internalized criteria of worth [38]. This dimension can be measured by means of real-time expressions of self-relevant emotions (i.e., positive to negative self-affect), such as pride or embarrassment [32, 33]. The second dimension, *self-competence*, refers to the experience of oneself as a causal agent with efficacy [38]. In the context of parent-adolescent interactions, this dimension can be measured by means of real-time autonomy-exhibiting behavior (i.e., autonomy to heteronomy), such as communicating an opinion or asserting one's self [34, 39, 40].

State self-esteem as a *process* was therefore operationalized as the moment-to-moment changes in the valence of expressed behavioral and emotional indicators of adolescents' self-esteem. As such, state self-esteem can be seen as a lower-order self-esteem construct that changes in quality (i.e., varying weight of autonomy versus self-affect) and intensity from moment to moment. This corresponds with the notion of self-esteem as "a positive or negative response to oneself that can take a variety of forms" ([41], p. 35). Concretely, the moment-to-moment changes in valence form a time series for each individual. We captured the time-varying trends of these time series using the Loess smoothing technique [42].

The use of observable expressions of self-affect and autonomy as underlying components of state self-esteem was first demonstrated in De Ruiter et al. [15], where the temporal variability of adolescents' state self-esteem was examined. The study showed that, firstly, this temporal variability demonstrated intrinsic dynamics that resembled a fractal process, and secondly, that this variability was significantly different from the kind of variability that would be generated from fluctuations around a stable baseline. As



such, this previous study—like others that have studied the temporal dynamics of self-esteem [16, 17, 26, 43]—did not test the role of the immediate context; nor did it examine differences between individuals' intrinsic dynamics. The current study builds upon those earlier findings by testing the simultaneous interplay between intrinsic dynamics of self-esteem and the extrinsic dynamics in the social context and by examining differences between individuals.

*1.3.2. Intrinsic Microlevel Dynamics: State Self-Esteem Variability and Recurring Self-Esteem Patterns.* Based on the SOSE model, state self-esteem processes (i.e., as lower-order processes of self-esteem) alone do not create *intrinsic dynamics* of self-esteem. Instead, intrinsic dynamics are expected to arise due to the constraint that self-esteem attractors have on state self-esteem processes.

"Self-esteem attractors" were operationalized as qualitatively different patterns of adolescents' lower-order self-esteem components that self-organized—and repeatedly recurred—across the interaction. We captured self-esteem attractors with Kohonen's self-organizing maps [44]. This is a clustering technique that finds structure in multivariate time-series data that have "self-organized" across the time series. It is widely used outside of psychology, but has been recently introduced to psychology for the use of studying intraindividual variability of multivariate time-series data [45]. The technique thus finds (recurring) structure that has emerged from iterations of the lower-order multivariate data and can be expressed as a higher-order construct, similar to attractors. As such, we do not define attractors by mathematical means, but by a qualitative theory of attractor mechanisms (i.e., self-organization from lower-order components into patterns, and repetition of said patterns across time). The qualitative attractors that we define and measure in the current study are in this sense *attractor-like*, in comparison to the definition of mathematical attractors.

Next, the "self-esteem attractor constraint" that underlies intrinsic dynamics of self-esteem was operationalized as the extent to which real-time transitions to and from specific self-esteem attractors coincided with specific changes in state self-esteem variability. This was done using state space grids [46, 47]. This is an application of the standard "state space" concept of dynamic systems to categorical dimensions, therefore dividing the state space into a grid. The grid depicts a two-dimensional (categorical) state space by portraying the dynamics between two synchronized streams of data. While this is often used to study the dynamics between two individuals, we have used it to study the dynamics between one lower-order stream of events (i.e., state self-esteem) and one high-order stream of events (i.e., transitions between self-esteem attractors). This operationalization reflects the landscape notion of self-esteem attractors, where each valley represents a different attractor state that pulls lower-order processes toward that point and where deeper valleys provide more constraint on lower-order variability than shallow valleys do. From this conceptualization, while a *strong* self-esteem attractor state is expressed, we would expect to observe limited state self-esteem variability. Moreover, we would expect each attractor to provide its own set of

constraints on lower-order variability, such that the expression of that attractor state corresponds with a certain range of state self-esteem valence (e.g., high self-esteem, but not low self-esteem). Thus, the repeated expression of that specific self-esteem attractor would correspond with state self-esteem returning to the same approximate levels as the previous time that attractor was active.

In summation, self-esteem attractor constraint was identified by each attractor's ability to limit the degrees of freedom of state self-esteem while it is expressed *and* by the attractors' ability to pull state self-esteem to the same approximate level each time it is active. As such, our definition of attractor constraint is based on qualitative theory of these mechanisms, just like our definition of attractors themselves. Our operationalization of attractor constraint is therefore of *constraint-like* behavior.

*1.3.3. Extrinsic Microlevel Dynamics: Parental Expressions of Emotions and Behavior.* As research shows that self-esteem is particularly influenced by significant others and their behavior (e.g., [48, 49]; Fogel, 1993), studying self-esteem processes in the context of parent-child interactions provides a theoretically solid foundation for assessing the impact of perturbations (i.e., extrinsic forces) on adolescents' self-esteem.

Perturbations are changes (such as changes in context, goals, or demands) that result in a shift in a state or pattern. The nature of a perturbation depends on the time scale that is considered [50]. For example, a move from primary school to secondary school can be considered a perturbation that occurs at a larger time scale, while a shift in the emotional intensity of a conversation can be considered a perturbation that occurs at a smaller time scale. Since we will be examining self-esteem changes that occur across real time, we are interested in these latter forms of moment-to-moment perturbations.

Moment-to-moment changes in parents' expressed emotions and autonomy support were treated as potential real-time perturbations (i.e., in the here and now). The reason for focusing specifically on parents' expressed emotions and autonomy support is based on the fact that adolescents are faced with the critical developmental task of achieving autonomy within the parent-child relationship while maintaining connectedness in the relationship [48, 51–53]. The extent to which this critical task is met is central in determining adolescents' sense of self [40]. As such, characteristics of the parent-child relationship that specifically support the achievement of this critical task are often associated with adolescents' self-esteem. This includes parental *expressions of connectedness* (i.e., closeness and warmth toward the child; [54])—facilitating the maintenance of connectedness in the relationship—and *autonomy support* (i.e., supporting or challenging the child's independence of thought and behavior; [55–57])—facilitating the achievement of autonomy within the relationship. These specific aspects of the parent-child interaction were therefore central in our study of the perturbations acting upon adolescents' state self-esteem.

We will refer to moment-to-moment changes of parental expressions of connectedness and support as changes in

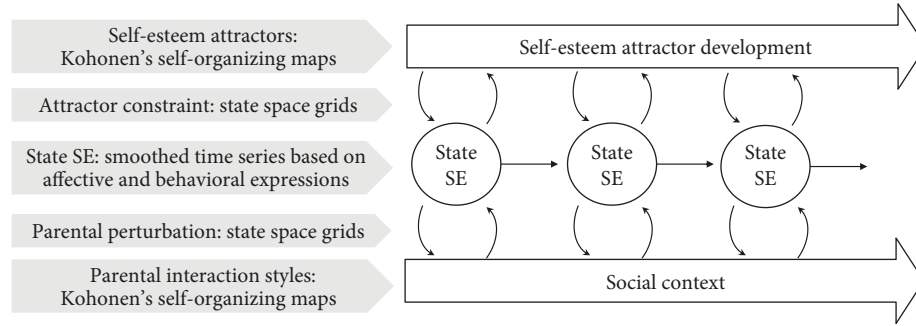


FIGURE 3: Overview of the methods used to capture the various processes involved in the interplay between self-esteem attractors and the immediate social context acting upon state self-esteem (SE).

“parental interaction styles.” We will map the real-time dynamics between these interaction styles and the adolescent’s state self-esteem, and when a real-time change in parental interaction styles corresponds temporally with a change in the valence of the adolescent’s state self-esteem, this will be referred to as a “parental perturbation.”

We captured real-time parental interaction styles using Kohonen’s self-organizing maps [44], and we mapped the moment-to-moment dynamics between these interaction styles and the adolescents’ state self-esteem with state space grids [46, 47].

In summation, in the current study we aimed to capture all processes involved in the continuous interplay between intrinsic dynamics and extrinsic forces acting upon state self-esteem (i.e., the processes outlined in Figure 3). We attempted to capture these processes with a number of different techniques, outlined in Figure 3 below. These techniques will be explained in more detail in Results.

## 2. Methods

**2.1. Participants.** Participants were thirteen adolescents (10 girls, 3 boys) and their parents (12 females, 1 male). The mean adolescent age was 13.6 (ranging from 12 to 15). The majority of the dyads were Dutch-speaking, with the exception of two English-speaking dyads (one American-Dutch dyad and one British dyad). Participation was voluntary, and children were rewarded after the interaction task was completed with a 5 Euro gift voucher. Parents gave informed consent for their children.

**2.2. Procedure.** Each dyad was video-recorded in their own home during a discussion. Each discussion was structured around three topics in which the aim of the discussion was to come to a mutual decision. The first discussion topic was a positive discussion topic (e.g., If you could have one super power, which would you have?). The second was a conflict topic relevant to each specific dyad at that moment, where the dyad was instructed to try to come up with a solution to their problem. The last discussion topic was a new positive topic comparable to the first (i.e., A-B-A design, Granic et al., 2007; [58]). In assigning both neutral and conflict topics, a range of self-evaluative emotions and behavior are potentially elicited [24, 58]. Dyads were told that they could move

on to the next topic when they felt they were finished, keeping in mind that they should take about five minutes for each topic. The dyads were reassured that there was no “right” or “wrong” thing to say or do and that the researchers are interested in their natural responses to each other. The researcher then left the dyads alone in a room of their choice for the duration of the filming. Afterwards, the observational videos were coded for their emotional and behavioral content.

**2.2.1. Coding Procedure.** Based on the video-recorded interactions, we coded adolescents’ affective and behavioral expressions of state self-esteem, and affective and behavioral components of parents’ broader interaction styles (see Measures, below). The raw data for the current study were previously used in De Ruiter et al. (2016)), where only the adolescents’ data were used.

Coding of emotions was largely based on the Specific Affect (SPAFF) coding system [59], where physical cues are used to indicate different emotions. Adaptations were made in order to distinguish between self-directed affect and other-directed affect and were data-driven (in accordance with the Grounded Theory approach; [60]). Coding of autonomous behavior was largely based on Savin-Williams and Jaquish’s behavior checklist for adolescents’ self-esteem [34]. This checklist was further expanded upon using on Noom et al.’s [61] framework of emotional, functional, and cognitive autonomy during adolescence. Coding of parental affect and behavior was based on theory regarding parental autonomy support and connectedness [48, 62].

Coding was event-based (using the program The Observer XT 10.5), such that a code was given for each relevant verbal/nonverbal expression across the interaction. Observers were extensively trained until at least 75% agreement was reached before coding commenced. Average between-observer agreement for coders who independently coded 10% of the event-based data was sufficient, with Cohen’s kappa = 0.69 for autonomy-related behavior for parent and adolescent, 0.82 for self-affect, and 0.74 for connectedness.

**2.3. Observational Measures.** Observational measures were obtained for both adolescents and the parents. For both, emotions were ordered from most aversive (e.g., shame) to most positive (e.g., pride), similar to the ordering of emotions

done in the studies by Hollenstein et al. [58, 63]. Behaviors were ordered from most autonomous (e.g., confronting the other) to the most heteronomous (i.e., submitting to the other; [61]).

**2.3.1. Adolescent Measures.** *Self-affect* is self-directed affect. This measure was used as an indicator for adolescents' state self-esteem. Both positive self-affect and negative self-affect were scored. Positive self-affect was scored on a scale of 0 to 3, which includes 0 = neutral, 1 = self-interest (e.g., adolescent speaks enthusiastically about an idea she/he has), 2 = humor (e.g., adolescent laughs in self-assured manner while speaking/behaving), and 3 = pride (e.g., adolescent compliments him-/herself). Negative self-affect was scored on a scale of 0 to -3, which includes 0 = neutral, -1 = embarrassment (e.g., adolescent speaks with eyes cast down), -2 = anxiety (e.g., adolescent fidgets and avoids eye contact while opposing parent), and -3 = shame (e.g., adolescent speaks in sad and serious tone during self-invalidation). Positive and negative self-affect could be simultaneously scored if verbal and nonverbal expressions conflicted. Note that *self-affect* only includes "self-conscious" emotions, which are socially situated emotions pertaining to the self (Tangney and Fischer, 1995). These are in contrast with emotions that are not self-conscious, such as affection or anger, which reflect appraisals of the context and concerns in an immediate relationship (Frijda, 2001).

*Autonomous actions* was used as an indicator for adolescents' state self-esteem. It was scored on an ordinal scale of -2 to 3 (the scale is not symmetrical as there were more categories for autonomous behavior compared to heteronomous behavior), where -2 = submission (e.g., adolescent changed opinion in accordance with what parent thinks without offering counter arguments), -1 = attitudinal heteronomy (e.g., adolescent expressed not knowing the answer to a question that did not require specific knowledge), 0 = neutral, 1 = attitudinal autonomy (e.g., adolescent contributed an idea), 2 = agency (e.g., adolescent initiated a change in discussion topic), and 3 = self-assertion/confrontation (e.g., adolescent rejected accusation made by the parent).

*Connectedness* is other-directed affect, which was scored for the adolescent during or directly following the parents' utterances or actions. This was coded to determine self-experiential incoherence, a conditional measure necessary to ensure that *true* state self-esteem is captured (see Self-Experiential Incoherence, below). Both positive connectedness and negative connectedness were scored. Positive connectedness was scored on a scale of 0 to 3, which includes 0 = neutral, 1 = other-interest (e.g., adolescent smiled while parent spoke), 2 = other-joy (e.g., adolescent laughed while/after parent spoke/acted), and 3 = affection (e.g., adolescent hugged parent). Negative connectedness was scored on a scale of 0 to -3, where 0 = neutral, -1 = other-disinterest (e.g., adolescent looked away and turned body away while parent spoke), -2 = other-frustration (e.g., adolescent responded to parent with whining tone), and -3 = contempt (e.g., adolescent expressed hurtful comment in sarcastic tone). Positive and negative connectedness was simultaneously scored if verbal and nonverbal expressions

conflicted. An example of this is if the adolescent verbally expressed connectedness by laughing when the parent told a joke, while expressing a hurtful comment toward the parent in a sarcastic tone.

**2.3.2. Parental Interaction Measures.** *Parental connectedness* is other-directed affect, which was scored for the parent during or directly following the adolescent's utterances or actions. The scoring for parental connectedness is the same as for the adolescent (see above).

*Parent self-affect* is self-directed affect. Both positive self-affect and negative self-affect were scored. The scoring for parental self-affect is the same as for the adolescent (see above).

*Autonomy management* was scored on an ordinal scale of -2 to 3, where -2 = confrontation/pressure to submit (e.g., parent criticized the child's idea and suggested own idea as alternative), -1 = parent controlled the child (e.g., correcting the child), 0 = neutral (e.g., parent neither supported nor challenged the child's autonomy), 1 = encouragement (e.g., parent encouraged the child to continue explaining his/her idea), 2 = small validation (e.g., parent provided minimal encouragement by nodding while the child spoke), and 3 = large validation (e.g., parent complimented the child).

**2.3.3. Self-Experiential Incoherence.** Self-experiential incoherence is a dummy variable that was scored for the adolescents and parents after coding (of the abovementioned measures) took place. Based on Kernis' [29] suggestions, this measure was scored if an individual's simultaneous emotional and behavioral codes suggest disingenuous behavior. This is the case in the following scenarios: positive self-affect *and* negative self-affect were coded, positive connectedness *and* negative connectedness were coded, or negative autonomy *and* positive self-affect were coded [29]. These instances all suggest that the individual is "misrepresenting their feelings" by not divulging negative behaviors or self-aspects ([29], p. 13). Kernis [29] states that, while the individual may be expressing positive self-aspects, such scenarios do not indicate *true* self-esteem [39]. As such, while positive self-affect and autonomy can be seen as indicators of positive state self-esteem, it is vital that these indicators are not considered in isolation from each other. In scenarios of self-experiential incoherence, indicators of positive self-esteem (i.e., positive autonomy or positive self-affect) would not indicate *true* positive self-esteem if considered in isolation.

In this study, we wanted to ensure that we were capturing processes of true self-esteem. Therefore, self-experiential incoherence was measured and used in our calculation (as a conditional variable) of state self-esteem (see Variability of State Self-Esteem, below). Self-experiential incoherence was also included for the parent as information regarding the extent to which the parent was behaving genuinely or ingenuously toward the adolescent during the interaction.

**2.4. Analysis Plan.** The general aim of the analyses was to attempt to map the various mechanisms involved in a complex dynamic systems model of self-esteem and to test whether they related to each other in ways that we would



expect given this conceptualization. We focused on attractor-like constraint that higher-order recurring patterns of self-esteem have on lower-order SSE variability, as well as the perturbing effects of the immediate social context on SSE variability (Figure 2). For this aim, only the *temporal order* of variability (of state self-esteem) and of transitions (of higher-order recurring patterns) was considered relevant. The focus was therefore on the structure of the time series, not on the absolute levels or content of self-esteem or the parental measures themselves (This is the first foray into testing the Self-Organizing Self-Esteem model and thus the first attempt to test simultaneous processes of attractor constraint and perturbations in the context of self-esteem. Therefore, the data only allow for estimations of these complex processes and for suggestions that formal attractors exist. For the purpose of efficiency, we will use “self-esteem attractor” to refer to attractor-like patterns and “attractor constraint” to refer to constraint-like behavior.).

The analysis consisted of a number of steps, where each step involves a different method. Here we provide an overview of each step in the analysis and the respective analytical method. The analytical methods themselves will be further elaborated on in the relevant results section:

- (1) Capturing moment-to-moment processes of
  - (a) Variability of state self-esteem (SSE)
  - (b) Transitions between “self-esteem attractors” using Kohonen’s self-organizing maps
  - (c) Transitions between “parental interaction styles” using Kohonen’s self-organizing maps
- (2) Using state space grids to map the temporal correspondence between the variability of SSE (from step 1) and
  - (a) Higher-order patterns of “self-esteem attractors” (from step 1b) to determine the level of “attractor constraint” on state self-esteem variability
  - (b) Higher-order patterns of “parental interaction styles” (from step 1c) to determine the level of “parental perturbations” on state self-esteem variability
- (3) Comparing the within-individual level of “attractor constraint” (from step 2a) with the level of “parental perturbations” (from step 2b) for each individual using a Monte Carlo bootstrapping method

### 3. Results

#### 3.1. Part 1: Capturing Moment-to-Moment Processes

**3.1.1. Variability of State Self-Esteem (Step 1a).** State self-esteem (SSE) time series were calculated based on the sum of the behavioral (i.e., autonomy) and affective (i.e., self-affect) indicators of the adolescent’s self-esteem for *each moment* in the interaction (see the section *Adolescent*

*Measures*, which describes the various observational measures). To ensure that *true self-esteem* was captured [29, 64], the presence of these indicators was not considered in isolation from each other. A positive affective or behavioral indicator was only deemed as a true indicator of positive self-esteem given the absence of a self-experiential incoherence code (self-experiential incoherence = 0). The calculation for  $SSE_t$  was conducted in Microsoft Excel (Version 2010) and is described by

$$SSE_t = (SA_t + AU_t); \quad \text{if } (SEI_t = 0); \quad \text{otherwise, } 0, \quad (1)$$

where  $SA_t$  is self-affect,  $AU_t$  is autonomy, and  $SEI_t$  is self-experiential incoherence at  $t_x$ .

The state self-esteem time series and the lower-order input time series (i.e., self-affect and autonomy) were smoothed for the subsequent analyses. This was necessary to smooth out the “neutral” moments (similar to missing data points) in the interaction that were coded when the individual did not do anything (because they were, e.g., waiting for the discussion partner to respond). During the coding process, a zero was coded for these neutral moments. When treated as a time series, this resulted in artificially large fluctuations (e.g.,  $t_1$  = child expresses frustration (connectedness = -2),  $t_2$  = child is silent while listening (connectedness = 0), and  $t_3$  = child continues to express frustration (connectedness = -2)). The coding of zeroes during moments in which an individual was silent therefore resulted in noisy time series. To remedy this, we smoothed the data to correct for this artifact of the coding process.

Smoothing was done with a LOESS smoothing technique [42], which is the most common method used to smooth noisy time series. Loess smooths by conducting a local regression around each score of the time series. We did this in a window of 20% of the data. The window is sequentially moved across the scores in the time series (i.e., a *moving window*). The values within the moving window are weighted on the score at that second. The smoothing process thus compresses the scale of the measures, while following the general trend of the data and thus protecting the temporal structure [65]. Given that only the temporal structure of changes in variables was important for our study (not the absolute level of variables), the change in scale did not jeopardize the validity of the current analyses. An example of the smoothed lower-order time series (self-affect and autonomy) and the state self-esteem time series is shown in Figure 4. The length of the time series across our sample was  $M = 847.3$  seconds ( $SD = 192.2$ ).

**3.1.2. Transitions between Higher-Order Patterns (Steps 1b and 1c).** We captured higher-order patterns of recurring self-esteem attractors and parental interaction styles using Kohonen’s self-organizing maps (SOM; [44]).

**(1) Kohonen’s Self-Organizing Maps.** Kohonen’s self-organizing maps is a data-mining technique that maps the spatial and temporal emergence of structure in time-serial

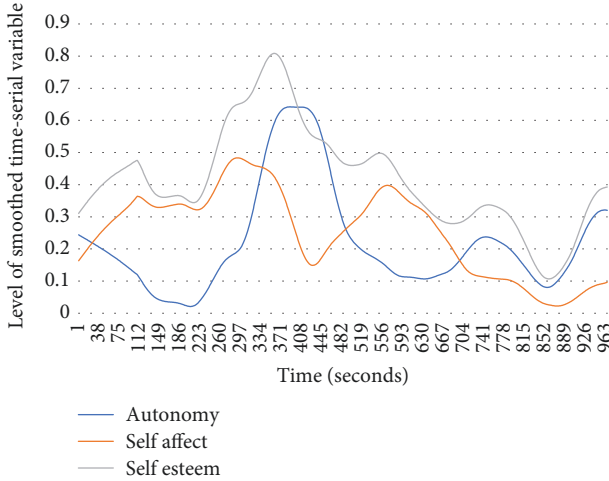


FIGURE 4: Example of an individual's lower-order time-series variables (self-affect and autonomy) and their state self-esteem time series.

data. The SOM analysis was done in the program Tanagra 1.4.41 [66], which is free data-mining software.

Using unsupervised learning algorithms, SOM derives a map of the data for each individual. A map is a small set of qualitatively different “clusters” that show the underlying structure of the individual's input data. An “unsupervised learning algorithm” means that the clusters are discovered in a recursive process by means of the input data and hence not specified by the researcher beforehand. The SOM learning process works by recursively comparing pairs of vectors: an empirical vector that represents the input data and a model vector (from the emerging map). The model vector is continuously calculated and updated based on the value of the empirical vector and its position on the time series. If the vectors differ, the model vector is altered slightly so that dissimilarity is reduced. This is repeated multiple times, where at each step an empirical vector is presented to a new model vector, until the map fully represents the structure of the empirical data. Through this process, the accuracy of the map continuously improves with each iteration as it “learns” to represent the structure of the data. When the learning process is finished, the final map optimally represents the organization of the data across time [44].

The resulting map reveals the organization of each individual's data as new higher-order output, represented by the moment-to-moment transitions between the recurring clusters. Because we used this technique to capture within-individual structure, each individual has a unique map (i.e., set of clusters). The clusters differ with regard to their quality and their temporal patterns of recurrence. Regarding the quality, each cluster is defined by the variables (i.e., input data) that are most salient in that specific cluster and by the relationships between the variables within the cluster (see the Appendix for an example of the quality of clusters for two individuals). This means that each variable can contribute to multiple clusters within an individual's map, such that each cluster represents a different relationship

between the same variables. Thus, rather than collapsing the “time” component of the data and determining the statistical similarity between the various variables, the SOM determines the dynamic correspondence between time-series variables [67].

Regarding the temporal patterns of each cluster, the SOM keeps track of the time point that each data point falls into the various clusters [68]. Therefore, the resulting clusters keep the “topological structure” (i.e., the relationship between data points *over time*) intact. Because of this, an individual's emergent map includes information regarding when, and for how long, each cluster is expressed across the time series. This information is in the form of a new (higher-order) time series, generated for each individual. The time series show the moment-to-moment transitions between the individual's clusters across the time span of their time series. This is the crucial information for the current study, as we are interested in the temporal pattern of these higher-order structures, rather than the idiosyncratic quality of the structures. This temporal pattern is what was used to determine the temporal correspondence with state self-esteem variability in step 2 of the analysis. The temporal recurrence of clusters is illustrated in the following section (in Figure 5).

This technique has been demonstrated and described in De Ruiter et al. [45] as a useful method for studying real-time development of multivariate data at the intraindividual level. For more specifics regarding the SOM algorithm and the specific learning rules, see Kohonen [44].

(2) *Kohonen's Self-Organizing Maps in the Current Study.* For the current study, we used the SOM technique to obtain a higher-order map (i.e., a collection of person-specific clusters) of each adolescent's self-affect, autonomy, and self-experiential incoherence. These idiosyncratic maps were our operationalization of the adolescents' “self-esteem attractors,” as they revealed qualitatively different patterns of adolescents' lower-order self-esteem components that self-organized—and repeatedly recurred—across the interaction (for our rationale, see *The Current Study: Empirically Testing the Interplay Between Intrinsic Dynamics and Contextual Forces*). When conducting SOM, the researcher must determine how many clusters will make up the map. Based on Wong et al.'s [26] finding that most participants revealed two attractors of self-evaluation during self-narratives, we captured two self-esteem attractors (i.e., a map consisting of two clusters) for each adolescent. For ease of interpretation, and because the content of the attractors is not relevant here, we call these clusters “self-esteem attractor 1” and “self-esteem attractor 2” for each adolescent.

Recall that the SOM analysis maintains the temporal structure of the emergent clusters for each individual and portrays this temporal structure as a new time series. These time series include the timing and duration of transitions between the two clusters. To illustrate, Figure 5 shows self-esteem attractor time series for two different individuals (A and B). As only the duration and transitions between each individual's clusters are relevant for this study, we have not included the SOM output that refers to the quality of the

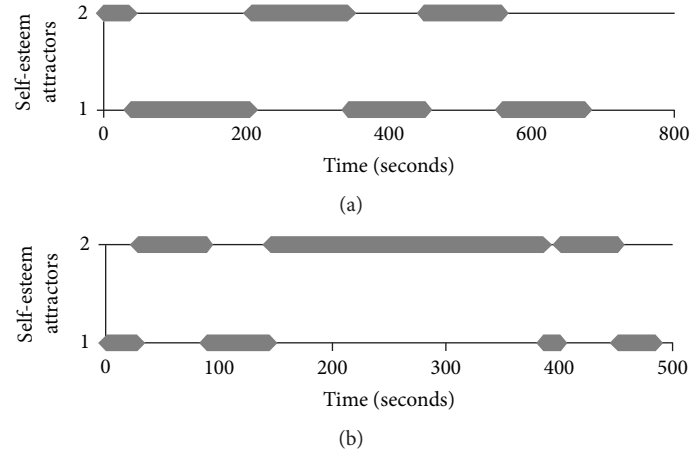


FIGURE 5: Empirical examples of self-esteem attractor time series across the dyadic interaction for two participants (a and b). The grey bars indicate the duration of time (i.e., seconds) that the self-esteem attractors (1 and 2) are expressed.

clusters (see the Appendix for the content output corresponding with participants A and B from Figure 5).

We also used the SOM technique to obtain a higher-order map of each parents' parental connectedness, autonomy management, and parental self-experiential incoherence. These maps were our operationalization of "parental interaction styles," as they revealed qualitatively different patterns of parental expressions of affect and behavior toward the child during the interaction. In order to make within-individual comparisons between parental interaction style transitions and transitions between self-esteem attractors, we also captured two parental interaction styles (i.e., a map consisting of two clusters) for each parent. We call these two clusters parental interaction style 1 and parental interaction style 2 for each parent.

**3.2. Part 2: Mapping the Temporal Correspondence between SSE Variability and Higher-Order Patterns.** In this step, we measured the extent to which transitions to and from individual's clusters (self-esteem attractors 1 and 2; parental interaction styles 1 and 2) coincided with specific changes in state self-esteem variability.

For self-esteem attractors, temporal correspondence with SSE variability refers to the level of "self-esteem attractor constraint." If the expression of a given self-esteem attractor (e.g., self-esteem attractor 1) predominantly corresponded with a certain level of SSE across the interaction (e.g., medium to high), and if the SSE level remained relatively stable (i.e., medium to high) while that self-esteem attractor (i.e., self-esteem attractor 1) was expressed, we refer to this adolescent's self-esteem attractors as having a high level of constraint on state self-esteem variability. This corresponds with the conceptualization that strong attractors have a strong pull on lower-order processes and that lower-order variability of lower-order processes is limited while the attractor is expressed (see The Current Study: Empirically Testing the Interplay Between Intrinsic Dynamics and Contextual Forces).

For parental interaction styles, temporal correspondence with SSE variability refers to the level of "parental

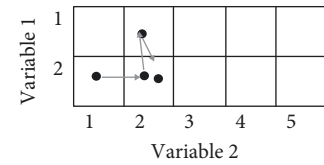


FIGURE 6: Illustration of four events of a hypothetical variable 1 ( $y$ ) and variable 2 ( $x$ ) in a state space grid.

perturbation." If the adolescent's state self-esteem level often changed at the same time as a change in parental interaction style and was not variable while this parental interaction style was expressed, we referred to this parent's interaction styles as having a high level of parental perturbation.

State space grid methodology was used to map these two processes (SSG; Hollenstein, 2013; [47]). This was done in the program GridWare 1.1 (Lamey et al., 2004). SSGs portray the dynamics of two streams of events across time. This is most commonly done for the streams of behavior between two individuals, but can be done for any two variables that have synchronized streams of categorical data. The sequence of events that occur between the variables is plotted as it proceeds in real time on a grid representing all possible event combinations. Each cell of the grid represents the simultaneous intersection of each variable. The events for one variable are plotted on the  $x$ -axis, and the events for the second variable are plotted on the  $y$ -axis. Any time there is a change in either variable, a new point is plotted in the cell representing that joint event and a line is drawn connecting the new point and the previous point. Thus, the grid represents the sequence of the system's events [69]. This is illustrated in Figure 6, with hypothetical variable 1 (with two possible events) on the  $y$ -axis and variable 2 (with five possible events) on the  $x$ -axis. Each dot represents the intersection between variables 1 and 2 at each moment, with four events plotted across time. The arrows represent the succession of steps, beginning with the dot on the left.

In the current study, we used SSGs to examine the within-individual dynamics between SSE and self-esteem attractors and between SSE and parental interaction styles

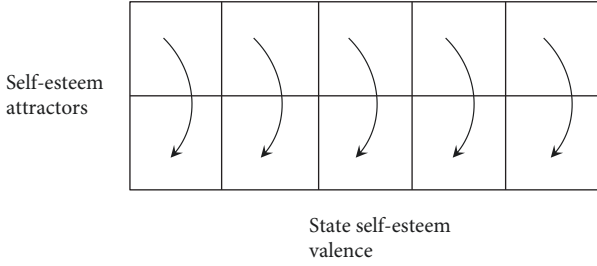


FIGURE 7: The intercell difference between an individual's two attractors was calculated for each level of state self-esteem. If the intercell difference was high across all levels of state self-esteem, this indicated that each level of state self-esteem predominantly occurred while one (but not both) self-esteem attractors were expressed (i.e., high temporal correspondence). If the intercell difference was low, it indicated that this specific range of state self-esteem levels was experienced irrespective of the self-esteem attractor that is expressed (i.e., low temporal correspondence).

to determine whether variability between the two streams temporally corresponded. We therefore plotted the sequence of state self-esteem events on the  $x$ -axis against the sequence of higher-order patterns (separately for trait self-esteem attractors and for parental perturbations) on the  $y$ -axis. We thus mapped the temporal correspondence with state self-esteem variability for the sequence of self-esteem attractor states and for parental interaction styles separately.

Because SSGs required ordinal data, it was necessary to first transform the smoothed state self-esteem time series (shown in Figure 4) into ordinal data. In line with other studies that use SSGs [69], we collapsed our continuous data into five categories: very low = 1, low = 2, medium = 3, high = 4, and very high = 5. Note that the absolute values of state self-esteem are not part of the analysis, as we only examined the temporal structure of transitions from one level to the other. Changing the scale for the use of SSGs therefore did not change the conclusions that can be drawn.

Aside from providing a graphical display of the stream of events between two variables across time, the SSG method also quantifies characteristics of the stream of events. We used the SSG to count the frequency of events in all possible cells for each individual's grids. Each individual had two grids: one for SSE ( $x$ ) against self-esteem attractors ( $y$ ) and one for SSE ( $x$ ) against parental interaction styles ( $y$ ). We used these frequencies to determine the extent to which each level of state self-esteem ( $x$  = very high, high, medium, low, very low) temporally corresponded with each higher-order cluster ( $y$  = self-esteem attractor 1 or self-esteem attractor 2 and parental interaction style 1 or parental interaction style 2). For each individual, the total number of events for self-esteem attractor 2 was subtracted from the total number of events for self-esteem attractor 1 within each level of state self-esteem (see Figure 7). The same was done for the grids with SSE against parental interaction styles. These frequencies were made proportionate to the total number of events for each level of state self-esteem ( $x$ ).

The formal calculation for temporal correspondence between state self-esteem variability and high-order variability is shown in Formula (2). When calculated based on the

temporal correspondence of SSE with self-esteem attractors 1 and 2, it refers to *self-esteem attractor constraint*, when calculated based on the temporal correspondence of SSE with parental interaction styles 1 and 2, and it refers to *parental perturbations*.

Self-esteem attractor constraint

$$\text{OR parental perturbations} = \sum_{i=1}^5 \left( \frac{x_i y_1 - x_i y_2}{x_i y_1 + x_i y_2} \right), \quad (2)$$

where  $x$  is the number of times that state self-esteem occurred for each cell on the  $x$ -axis (and where  $i$  = the level of state self-esteem; i.e.,  $i = 1, 2, 3, 4, 5$ ), and where  $y$  is the number of times that each higher-order cluster occurred for each cell on the  $y$ -axis (where  $y_1$  = self-esteem attractor 1 or parental interaction style 1 and  $y_2$  = self-esteem attractor 2 or parental interaction style 2, depending on which is being calculated). Temporal correspondence with SSE ranges from 0 to 1, where 0 = no correspondence and 1 = perfect correspondence.

To illustrate the above calculation of temporal correspondence, if "very low" state self-esteem events ( $x = 1$ ) frequently occurred while *both* self-esteem attractors 1 and 2 were expressed ( $x = 1$  events were dispersed across both self-esteem attractor 1 and self-esteem attractor 2), this would indicate that there was low temporal correspondence between "very low" state self-esteem and any one specific attractor. As such, this indicates that self-esteem attractors 1 and 2 are weak attractors. In contrast, if "very low" state self-esteem events ( $i = 1$ ) frequently occurred with only *one* of the two attractors (e.g.,  $x = 1$  events were only found in self-esteem attractor 1), this would indicate that there was high temporal correspondence between "very low" state self-esteem and self-esteem attractor 1. As such, this suggests that self-esteem attractor 1 is a strong attractor. While this example only uses  $x = 1$ , this was applied for all levels of state self-esteem (1–5) and for each individual separately.

Figures 8(a) and 8(b) are examples of empirical state space grids for two individuals (i.e., output from the GridWare program). The grids portray the sequences of events for self-esteem attractors ( $y$ ) against SSE variability ( $x$ ). Figure 8(a) shows an adolescent with a relatively high level of self-esteem attractor constraint (0.46), and Figure 8(b) shows an adolescent with a relatively low level of self-esteem attractor constraint (0.11).

Figure 8(a) shows that the two self-esteem attractors differentiated between levels of state self-esteem valence, where self-esteem attractor 1 exclusively occurred at the same time as high and very high state self-esteem levels (i.e., cells 4 and 5), while self-esteem attractor 2 exclusively occurred at the same time as very low and low state self-esteem levels (i.e., cells 1 and 2). With regards to our earlier formula for calculated self-esteem attractor constraint, this means that the absolute difference in the number of observations between self-esteem attractor 1 ( $x_i y_1$ ) and self-esteem attractor 2 ( $x_i y_2$ ) is relatively high, resulting in a high absolute level of self-esteem attractor constraint (0.46). In contrast, Figure 8(b) shows that the two attractors did not



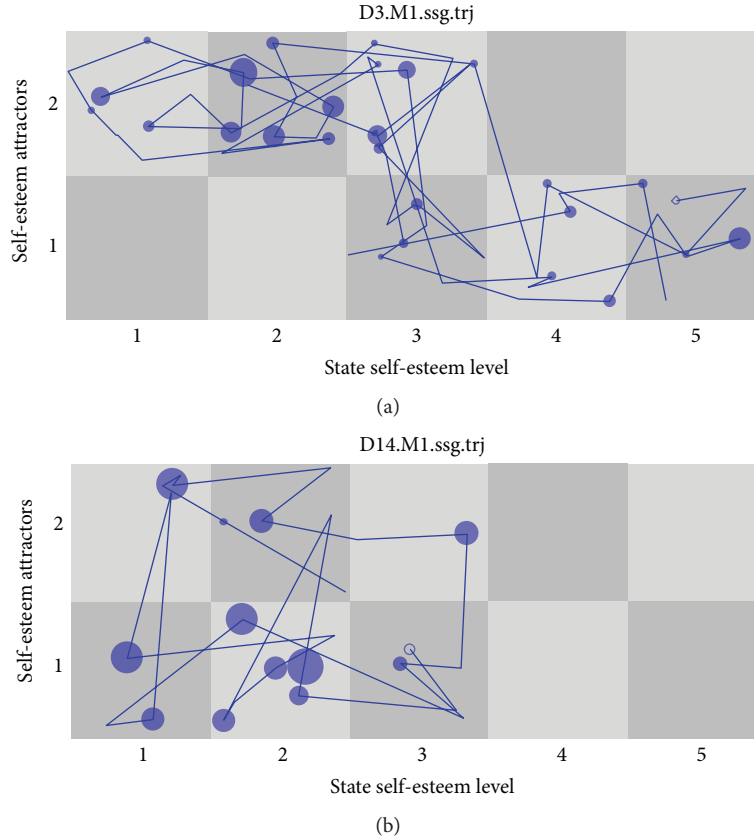


FIGURE 8: Two examples of state space grids from our data portraying the time series for self-esteem attractor expression (y-axis) against the time series for state self-esteem (x-axis). The lines indicate direction of movement between events, and circles indicate duration of events. (a) Illustrates an individual with a high level of self-esteem attractor constraint, while (b) illustrates an individual with a low level of self-esteem attractor constraint.

differentiate between levels of state self-esteem valence, where self-esteem attractors 1 and 2 corresponded with the same state self-esteem levels: very low, low, and medium (i.e., cells 1 to 3). This means that the absolute difference in number of observations between self-esteem attractor 1 ( $x_i, y_1$ ) and self-esteem attractor 2 ( $x_i, y_2$ ) is relatively low, and a low absolute level of self-esteem attractor constraint (0.11).

**3.3. Part 3: Testing the Interplay between Attractor-Like Patterns of Self-Esteem and Parental Perturbations.** What was of interest in this step of the analysis was the within-individual comparison of self-esteem attractor constraint (i.e., temporal correspondence of self-esteem attractors with SSE variability) relative to parental perturbations (i.e., temporal correspondence of parental interaction styles with SSE variability).

We split the sample of adolescents into two (based on a median split of the level of self-esteem attractor constraint) to examine the within-individual difference scores (between the level of temporal correspondence with self-esteem attractors and with parental interaction styles) for adolescents with relatively “strong” self-esteem attractors compared to adolescents with relatively “weak” self-esteem attractors. We called the group of adolescents with “strong” self-esteem attractors profile 1, and we called the group with “weak” self-esteem attractors profile 2.

Within-individual levels of temporal correspondence with SSE are shown for self-esteem attractors and parental interaction styles, for profile 1 and profile 2, in Figure 8 below. The figure shows that the within-individual differences were in the expected direction for both profile 1 and profile 2. Specifically, for all adolescents in profile 2 (i.e., relatively “weak” self-esteem attractors), individual levels of parental perturbations were stronger than individual levels of self-esteem constraint were. This is in line with the SOSE conceptualization that state self-esteem will be more vulnerable to perturbations from the social context for individuals with weaker self-esteem attractors. The differences were in the opposite direction for profile 1: Figure 9 shows that all adolescents in profile 1 (i.e., “strong” self-esteem attractors), except for one, show higher levels of temporal constraint for self-esteem attractors relative to parental interaction styles. This corresponds with the SOSE suggestion that state self-esteem will be less perturbed by changes in the social context for individuals with stronger self-esteem attractors.

To provide a confirmatory test of the above differences, we used the Monte Carlo bootstrapping method. This method compares the real data to permutations of the data based on resampling. With each resample, a specific property of the real data is compared to that in the sampling distribution, where the null hypothesis is that there is no difference. In the current study, we used 5000 permutations of the data.

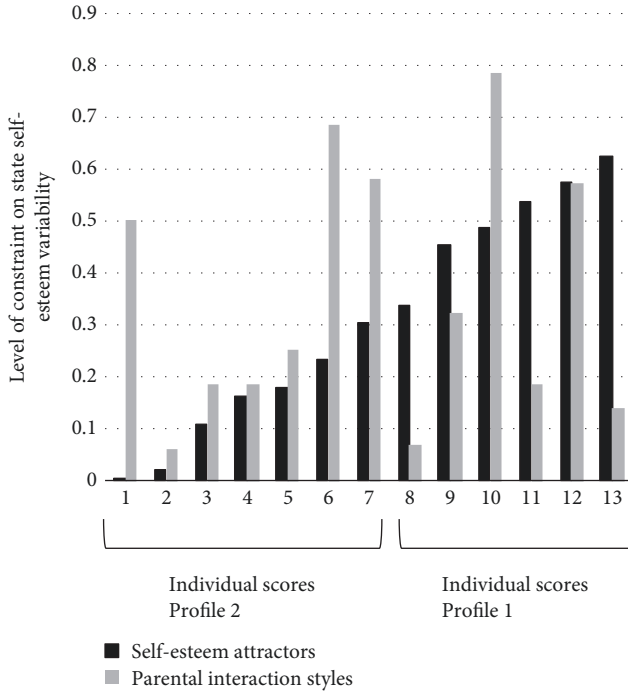


FIGURE 9: Individual levels of temporal correspondence between SSE and self-esteem attractors with SSE and parental interaction styles.

The Monte Carlo analysis does not rely on assumptions about the population from which the data came (such as normality or homoscedasticity), making it a suitable method for small sample sizes such as ours. Because assumptions about the population are not made, the aim of the analysis is not to estimate characteristics about the general population. Instead, the aim is to ascertain if this configuration of data could have occurred randomly or not. The conclusions drawn are thus related to the sample itself and the implications that this has for the theory that we are interested in.

First, we tested the hypothesis that the average self-esteem attractor constraint for profile 1 ( $M_{\text{self-esteem attractor constraint}} = 0.50$  (SD = 0.09)) is larger than for profile 2 ( $M_{\text{self-esteem attractor constraint}} = 0.15$  (SD = 0.10)), with  $p = 0.001$ . The Monte Carlo method was also used to test the hypothesis that the average self-esteem attractor strength is larger than the average parental perturbations in profile 1 ( $M_{\text{self-esteem attractor strength}} = 0.50$  (SD = 0.09) >  $M_{\text{parental perturbations}} = 0.34$  (SD = 0.10)), while the average parental perturbations is larger than the average self-esteem attractor strength in profile 2 ( $M_{\text{parental perturbations}} = 0.35$  (SD = 0.21) >  $M_{\text{self-esteem attractor strength}} = 0.15$  (SD = 0.10)), with  $p = 0.012$ . Therefore, the two profiles of attractor constraint were significantly different in our sample, and these two profiles show significantly different relationships with the effect of parental perturbations.

#### 4. Discussion

In this study, we examined the interplay between adolescents' intrinsic dynamics of self-esteem and extrinsic forces at the

micro level (i.e., from moment to moment). First, with regards to the intrinsic dynamics, we found that our sample of adolescents showed large variation regarding how much constraint adolescents' "self-esteem attractors" had on their state self-esteem variability, indicating different levels of attractor "strength." The sample could be characterized by a "strong attractor" profile and a (significantly different) "weak attractor" profile. Our measure of self-esteem attractor constraint was based on the extent to which transitions to and from specific self-esteem attractor-like patterns occurred at the same time as specific changes in state self-esteem valence. For this, we used observable indicators of adolescents' self-esteem—self-affect and autonomous actions—during parent-child interactions.

This first finding provides proof of concept of "self-esteem attractors," as described in the Self-Organizing Self-Esteem (SOSE) model and for individual differences in the landscapes that these attractors form. Specifically, the SOSE model draws from the complex dynamic systems perspective and suggests that self-esteem is best conceptualized as a system of nested self-esteem levels (lower-order processes such as state self-esteem and higher-order processes of recurring patterns, i.e., attractors). From this model, individuals have self-esteem attractors that "attract" lower-order processes (i.e., state self-esteem), where each self-esteem attractor within an individual's landscape pulls this lower-order process in a different direction.

While previous studies have found evidence for intrinsic dynamics of self-esteem [15–17, 43], the SOSE model suggests that these intrinsic dynamics specifically stem from the pull by various self-esteem attractors on state self-esteem variability. In this way, self-esteem is seen as a kind of habit or tendency that the individual is more likely to fall into with regard to their moment-to-moment experiences of self, compared to alternative potential tendencies.

The SOSE model suggests that self-esteem attractors can become entrenched over time if they are frequently "visited" and that individuals will thus differ in how entrenched their self-esteem attractors are. Individuals with more entrenched self-esteem attractors experience more constraint (i.e., more pull) on their state self-esteem processes. Our sample supports this prediction regarding individual differences in how entrenched self-esteem attractors are, as indicated by varying levels of constraint on state self-esteem. The variation found in our sample also attests to the sensitivity of our measure of "attractor constraint."

This finding is in line with previous studies that found individual differences in how stable self-esteem is and how abruptly self-esteem shifts, where more unstable self-esteem is related to not having a clear sense of self that provides a stable frame of reference for experiences of self (i.e., low *self-concept clarity*; Nezlek and Plesko, 2001; [16]). From a complex dynamic systems perspective, this can be interpreted as indicating that a lack of clear sense of self indicates weak attractors, as these do not provide much stability to individuals' experiences of self [16, 26, 70].

These previous studies examined self-esteem variability as one process and related characteristics of this process to levels of self-concept clarity. While self-concept clarity was

theorized to indicate something about individuals' attractor landscapes (where low self-concept clarity may be conceptually similar to having weak attractors; [16]), our study is the first to study the moment-to-moment association between two nested, but separate, self-esteem processes: self-esteem attractors and state self-esteem variability.

Our second finding provides convergent validity for the conceptualization of "self-esteem attractors." If the higher-order patterns measured in our study can indeed be conceptualized as "attractors," these patterns should demonstrate additional properties of attractors. We found evidence of this. Specifically, the self-esteem attractors that were characterized as relatively *strong* versus *weak* (based on their intrinsic dynamics) demonstrated a key property of *strong* versus *weak* attractors, respectively, based on their interplay with extrinsic forces. We found that potential external perturbations (stemming from changes in parental interaction styles) on state self-esteem were *weaker* than the intrinsic dynamics (i.e., constraint of self-esteem attractors on state self-esteem) for adolescents in the profile characterized by strong self-esteem attractors. In contrast, potential external perturbations (stemming from changes in parental interaction styles) on state self-esteem were *stronger* than the intrinsic dynamics (i.e., constraint of self-esteem attractors on state self-esteem) for adolescents in the profile characterized by weak self-esteem attractors. This provides direct support for the prediction that "strong" attractors allow for fewer perturbations from extrinsic forces, while "weak" attractors allow for more perturbations on state self-esteem from extrinsic forces [19].

This is an important finding, as it has been previously shown that daily experiences of self-esteem show a temporal pattern that suggests a pull between preservation of previous levels and adaptation in the direction of new information [43]. This previous research suggests that attractor states may underlie the preservation of previous levels and that contextual perturbations may underlie the adaptations in new directions [43]. However, these underlying mechanisms were not explicitly operationalized or tested.

Our study thus expands upon previous research by explicitly measuring attractor constraint and studying its temporal association (at the within-individual level) with state self-esteem. As such, this was the first attempt to explicitly test the push and pull between attractor states and contextual perturbations. While taking new methodological steps, our findings thus contribute to a line of emerging research that collectively supports the notion that individuals have attractors of self-experiences and that these attractors can provide stability to individuals' experience of the self, depending on how strong the attractors are [16, 26, 70].

**4.1. Implications for the Ontology of Self-Esteem.** The current findings are highly relevant for the longstanding debate as to whether self-esteem is best conceptualized as a *stable* trait or a *variable* state [71, 72]. Recent studies are moving this debate away from the "either or" perspective, showing that self-esteem consists of *both* a relatively stable (but slowly evolving) trait element and a variable state element [12, 13, 73]. Our findings are in line with this suggestion and go

further by describing the precise nature of the stable component and the variable component as well as the mechanism underlying their relationship.

Specifically, it has long been suggested that state self-esteem fluctuates around a resting "baseline" level [8]. This has important implications for the conceptualization of the stable component of self-esteem and for the variable component. First, the stable component of self-esteem is commonly seen as a baseline level that is informative as a *description* of an individual's central tendency. This is demonstrated when repeated measures of state self-esteem are averaged in order to gain a measure of an individual's "true" level of self-esteem (i.e., of trait self-esteem) [5].

Our findings suggest that the "stable" component of self-esteem is not a resting baseline level, but a *dynamic mechanism*. Self-esteem attractor states provide stability to state self-esteem experiences by attracting future state self-esteem experiences in the direction of previously developed patterns of self-experience. While the quality of these attractor states (e.g., positive or negative self-esteem) can be informative about an individual's self-esteem tendency, our alternative conceptualization suggests that this stable component is more than a description of this tendency.

Next, the common conceptualization of self-esteem has important implications for the conceptualization of the variable component of self-esteem (i.e., state self-esteem). Specifically, it is usually assumed that state self-esteem fluctuations occur in response to "incoming information relevant to relational evaluation" ([9], p. 2). Therefore, state self-esteem fluctuations are seen as a "subjective index or marker of the degree to which the individual is being included versus excluded by other people" ([10], p. 519), where "cues that connote high relational evaluation raise state self-esteem, whereas cues that connote low relational evaluation lower state self-esteem" ([9], p. 2). In short, the cornerstone of the dominant conceptualization of state self-esteem is that variability of state self-esteem is due to external social forces and that each fluctuation indicates characteristics of the immediate social context (e.g., degree of being excluded).

Our findings suggest that, while state self-esteem is responsive to the social context (in this case, parental support and affect during interactions), the degree of responsivity may be partly determined by the intrinsic dynamics of self-esteem. State self-esteem variability is thus not just indicative of the "degree to which the individual is being included versus excluded by other people" ([10], p. 519) but also of the strength of an individual's self-esteem attractor states. As such, a negative state self-esteem experience, for example, is not only the result of "cues that connote low relational evaluation" ([9], p. 2), but it is potentially also a result of a pull toward a negative self-esteem attractor.

The interplay between contextual forces and intrinsic forces acting upon state self-esteem has important implications for understanding the role that parents have on adolescents' self-esteem specifically. While it has often been shown that parents have an important influence on adolescents' general level or future development of self-esteem (e.g., [48, 74]), our study contributes to the understanding of the moment-to-moment influence that parents have on

adolescents' self-esteem. More specifically, our findings shed light on why some adolescents' self-esteem may be less susceptible to their parents' support or expressed affect than others, depending on how much their own self-esteem attractors are "pulling" on their state self-esteem processes. If adolescents' self-esteem attractors are highly entrenched and have a high level of constraint on their state self-esteem variability, any moderate changes that parents make to their behavior and emotional expressions during interactions may have a limited effect on their child's state self-esteem. Therefore, while parents may be rightly encouraged to interact with their adolescent children in a way that displays more autonomy support and emotional relatedness [48], these efforts may not be met with the expected positive effects on their child's state self-esteem if the child's self-esteem attractors are highly entrenched.

**4.2. Limitations and Future Directions.** It was beyond the scope of the current study to investigate where individual differences in self-esteem attractor constraint come from. It may be that these differences represent relatively stable individual differences (in line with previous suggestions that individuals differ with respect to how much they base their self-evaluation on others' evaluation, e.g.; [28, 71]). On the other hand, individual differences may also represent differences in developmental phases of self-esteem.

The SOSE model suggests that individuals' self-esteem attractor landscapes significantly change during important transition phases in life [19]. During this time, old attractors are potentially abandoned (such that they are infrequently visited, making them shallower), and new attractors are beginning to form. During such a phase, the individual's attractor landscape therefore consists of weak attractors, resulting in more variability of lower-order processes [23].

In line with this, it has indeed been shown that state self-esteem becomes more variable during a transition phase [12]. As adolescence is a period of significant change in self-esteem [31, 75], it is likely that adolescence is thus also a period in which self-esteem attractors re-form and thus weakly constrain state self-esteem. Given that our sample consisted of preadolescents, we might expect that the adolescents in our sample already entered a period of significant developmental changes in self-esteem. However, age itself is not a good proxy for developmental transition phases [76]. Therefore, it is more likely that some adolescents had already entered such a transition phase while others had not (yet). This would account for the individual differences in attractor strength in our sample.

Future studies are needed to closely examine the extent to which individual differences in attractor strength are stable individual differences, and in that case, whether these differences are related to differences in how people evaluate themselves (i.e., evaluation based on others' evaluations or not, e.g.; [28, 71]). It may be that different ways of evaluating one's self somehow prevents the entrenchment of any specific self-esteem attractor. Longitudinal studies are necessary to explore this, as only then is it possible to determine whether attractor states become weaker versus stronger over time, when, and for whom.

In our study of attractor strength, we made no distinction between positive versus negative parental interaction styles. Research shows, however, that the effect of negative events on self-feelings of low self-esteem individuals is smaller than the effect of positive events on self-feelings of high self-esteem individuals [28]. If we assume that self-esteem attractors underlie trait self-esteem, these findings might suggest that individuals with negative self-esteem develop stronger self-esteem attractors. As such, only a small external push in the direction of the attractor (i.e., a small negative event) results in a large drop in state self-esteem. Future research is necessary to examine whether negative self-esteem attractors indeed become more easily entrenched over time and whether this explains a higher reactivity to negative daily events.

In this study, we tested the dynamic interplay between multiple complex dynamic systems principles that have not been previously applied in the context of self-esteem, including attractor constraint and contextual perturbations. As such, our operationalizations of these constructs were based on a marriage between complex dynamic systems theory and self-esteem theory, and not on previously validated measures. As these process concepts are not readily studied in psychology, our study illustrates an initial attempt to do so as thoroughly as possible. Future research should further explore these operationalizations and their validity.

Additionally, the current study did not examine all aspects relevant to a complex dynamic systems conceptualization of attractor landscapes. Specifically, an individual's attractor landscape is characterized by attractors *and* repellers, where repellers define the boundaries between attractors that the system avoids and cannot easily reach (such that a relatively large amount of energy would be required) or maintain (such that a relatively large amount of instability would arise if reached). The current study focuses on attractors because the notion of attractors lends itself more directly to self-esteem theory (i.e., where self-esteem—as a trait—is also characterized as being a specific self-evaluative tendency that an individual is drawn to). For this reason, attractors are also central in the Self-Organizing Self-Esteem model, which provides the foundation for the current study. However, the notion that some experiences of self-esteem are avoided is another area that requires additional research. Wong et al. [26], for example, have explored this by examining highly unstable points of self-evaluation. Future studies are needed to further explore the dynamics of self-esteem repellers, by studying both the energy needed to reach such points and the level of stability observed if those points are reached.

## 5. Conclusion

The variability of state self-esteem is an important characteristic of self-esteem, but the source of that variability is not well understood. A strength of the current study is the use of real-time dyadic data and time series analyses. This allowed us to investigate the moment-to-moment dynamics between adolescents' state self-esteem variability, the expression of their self-esteem attractors, and parental perturbations. In doing so, we found that the adolescents



TABLE 1: Examples of self-esteem attractor characterizations for two participants (A and B).

Percentage of time expressed	Participant A		Participant B	
	SE Attractor 1 (58.2%)	SE Attractor 2 (41.8%)	SE Attractor 1 (27.4%)	SE Attractor 2 (72.6%)
	Test value network characteristics			
Self-affect	17.19	−17.19	9.14	−9.14
Autonomy	−13.47	13.47	17.30	−17.30
Self-experiential incoherence	−10.9	10.9	4.65	−4.65

Note. SE = self-esteem.

demonstrated attractor-like patterns of self-esteem. For some adolescents, these self-esteem attractors were “strong” and for others they were “weak,” as defined by the level of constraint that they had on lower-order processes of self-esteem (i.e., state self-esteem). Thus, individuals differed in the nature of their intrinsic dynamics of self-esteem. For adolescents with “strong” self-esteem attractors, we found that parental perturbations on state self-esteem were *weaker* than their self-esteem attractors. For adolescents with “weak” self-esteem attractors, we found that parental perturbations were *stronger* than their self-esteem attractors.

These findings bring us closer to understanding how the process of adolescents’ state self-esteem is shaped from moment to moment during parent-child interactions. By explicitly examining the external forces from parents and adolescents’ attractor constraint acting upon state self-esteem, this study helps to integrate two perspectives on self-esteem: the common approach that stresses the role of social cues [10] and emerging studies that stress the role of intrinsic dynamics [15–17, 26, 43, 77]. As such, this study contributes to more a more nuanced conceptualization of the variable and stable components of self-esteem.

This study provides support for the ontology of self-esteem as a complex dynamic system, and it sets the groundwork for future studies to further explore the mechanisms that underlie self-esteem processes. By empirically illustrating these mechanisms, we hope that our study will encourage researchers in the social sciences to further explore the implications of conceptualizing self-esteem and related concepts (such as personality, attitudes, etc.) from a complex dynamic systems perspective.

## Appendix

Figure 5 demonstrates how individuals can differ with regard to the temporal pattern of variability between self-esteem attractors 1 and 2. Aside from the temporal variability between self-esteem attractors, the self-esteem attractors differed in content, both within and between individuals, with regard to the weight of the emotional versus behavioral experiences of self and the positivity or negativity of the various measures. To illustrate, the characterization of the two self-esteem attractors for participants A and B (from Figure 5) are displayed in Table 1. The table shows the percentage of time during which each self-esteem attractor was expressed across the entire dyadic interaction for each individual. The

extent to which each self-esteem attractor was characterized by each self-experiential variable is indicated by the *test value* (For more information, see the “Understanding the ‘test value’ criterion” tutorial provided by Tanagra (<http://data-mining-tutorials.blogspot.nl/2009/05/understanding-test-value-criterion.html>)).

The test value shows how much weight each component has in determining the expression of that specific self-esteem attractor, where higher absolute values indicate a higher weight. The test value is deduced based on a statistical within-individual test of a comparison of means (the mean value across the entire time series compared to the mean value during the duration in which the specific cluster is active). For each self-esteem attractor, the component with the highest absolute test value is the component that—when experienced (with the relevant valence)—is most likely to trigger the expression of that specific attractor. For example, for participant A, it was likely that self-esteem attractor 1 was triggered when positive self-affect was experienced, given that self-affect had the highest absolute test value (test value = 17.19), and it was likely that self-esteem attractor 2 was triggered when negative self-affect was experienced (test value = −17.19). For participant B, the valence of autonomous self-experiences was most pivotal (test value = 17.30 and −17.30 for self-esteem attractors 1 and 2, resp.).

Because we defined two attractors for each individual, the emergent attractors were triggered by opposing levels of each component (i.e., self-affect, autonomy, and self-experiential incoherence). This can be seen in Table 1, where (within each individual) the test values of the network characteristics for attractor 1 were opposite in valence from those for attractor 2. The absolute values of test values differed between individuals, however, indicating a between-individual difference in weight regarding the various self-experiential components.

## Data Availability

Raw video material and Excel files are stored on the secure network drive of the University of Groningen (UWP Data Storage), to which only I and the data manager have access. This storage facility is protected and secure and is compliant with the University of Groningen Research Data Policy. Anonymous data can be made available for reuse through DANS (Data Archiving and Networked Services) upon request.

## Ethical Approval

All procedures were in accordance with the ethical standards of the Ethical Committee Psychology of the University of Groningen in the Netherlands.

## Consent

Informed consent was obtained from all individual participants in the study.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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